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Development of gypsum plasterboard embodied with microencapsulated phase change material for energy efficient buildings

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ABSTRACT

Phase change materials (PCMs) have been used in the development of building materials with higher thermal energy storage capacity. Especially, PCM incorporated gypsum plasterboard has been described to decrease the cooling demand of building by up to 35%. However, it's significantly important to fabricate and characterise the thermal/physical properties of PCM-gypsum plasterboard accurately. This paper presented the fabrication process and property measurement of gypsum plasterboard integrated with microencapsulated PCM (mPCM). Property measurement included scanning electron microscope (SEM) technique, sting, density measurement, compressive strength test, and thermal conductivity testing. The characterisation results show that: (i) the gypsum plasterboard enhanced with 5% and 15% PCM claim 5.36 and 4.34 MPa respectively; (ii) with the addition of 15% PCM, the gypsum plasterboard presented the lowest value of thermal conductivity as 0.139 W/mK; (iii) The mPCM-gypsum plasterboard also operates longer period of time than gypsum plasterboard with higher temperature of roughly 1.5 °C especially during discharging period; (iv) The mPCM-pasteboard provided 0.4 W/min higher stored energy than gypsum plasterboard due to the addition of mPCM.

1. Introduction

The integration of phase change materials (PCMs) in building components improves the thermal criteria and achieve higher thermal comfort, especially in lightweight construction materials [1]. The building materials integrated with PCM increase the thermal energy storage capacity of building components without changing building fabric's temperature [2]. PCM for the lightweight building envelope is the most suitable solution for implementing PCM into buildings. They can be very effective for transferring the heat and cooling loads away from the peak demand times. The impacts of PCMs in concrete, lightweight wall, and wallboard are different. For instance, the PCM enhanced concrete cubicles present much higher fluctuations up to 18 °C [3]. In addition to the energy saved by the reduced cooling load, the lower surface temperatures of the lightweight wall result in greater comfort [4]. The heat flow of the wallboard can be reduced from 8.5% to 77.9% with using PCMs [5]

PCM incorporation with gypsum is one of the most common and popular materials to use in building construction due to the advantages of gypsum which are low prices, fire-resistant, aesthetics, and environmentally friendly. Also, the gypsum material can easily be used for internal/external wall and ceilings [6]. Hence, Table 1 summarizes the article investigating the performance of PCM integration with gypsum during the last 5 years.

According to Table 1, previous researches concluded that there are increasing advantages of applying the PCM impregnated gypsum plasterboard into building structure. First, the gypsum plasterboard-filled with 45% PCM stores at least 3 times more energy than a typical gypsum board and brick-wall [17]. The gypsum board integrated with PCM is also more thermally insulating than the ones without PCM since the addition of PCM reduces the thermal conductivity thereby increasing the heat capacity of gypsum [7,9]. For example, the gypsum board integrated 25% of fatty ester PCM has 25% lower thermal conductivity compared to the ones without PCM [7]. In the meantime, PCM-enhanced gypsum composite shaves the room temperature swing by 46% as the shape stabilized PCM plate is more efficient in the utility rate of latent heat [18]. Thus, the gypsum plasterboard with a form stable-composite PCM keeps the room temperature in comfort

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Table 1
Summary of studies on investigating the effect of PCM into gypsum.

References	Author/year	Building material	PCM type	Key findings
[7]	Serrano et al. (2015)	Gypsum	fatty ester PCM	Gypsum plasterboard integrated with 25% PCM has higher thermal insulation than the common gypsum and also has 41% higher average heat capacity thanks to the latent heat capacity of PCM.
[8]	Karaipekli and Sari (2016)	Gypsum powder	form stable composite PCMs (Pumice)	Gypsum blocks with a form-stable composite PCMs improved the ability to keep the indoor air temperature at a comfortable zone for a longer time thereby reduce the building energy usage.
[9]	Serrano et al. (2016)	Hemihydrate gypsum	mPCM Micronal®DS5008	Adding 10% in weight of PCM, gypsum composite presents the best thermal response, lower thermal conductivity, and higher heat capacity.
[10]	Lachheb et al. (2017)	Gypsum plaster	Micronal® DS5001X microcapsules	An increasing amount of additional PCM decreases the heat flux and temperature fluctuations greatly. The heat capacity of gypsum plaster is improved due to increasing additions of PCM.
[11]	Jeong et al. (2017)	M−30 gypsum	Hybrid shape stabilized PCM	The hybrid shape stabilized PCM increases the thermal heat capacity and thermal conductivity of gypsum block, for instance, the addition of 30 wt% PCM claims the highest value.
[12]	Sharifi et al. (2017)	Gypsum	Paraffin blend	The HVAC system energy requirement was reduced by 17% yearly, particularly, 6% of heating requirement and 35% of cooling demand by using PCM-gypsum plasterboard.
[2]	Xie et al. (2018)	Gypsum Powder	Graphite-modified mPCM	The influence of specific heat and heating conductivity to the heat release time is limited. However, an additional PCM layer would increase the wall surface temperature and heat flux during the heat storage process.
[13]	Singh and Bhat (2018)	Gypsum	Phase change material	The room inside temperature swings can be reduced by using PCM-gypsum board attached to the roof.
[14]	Gnanachelvam et al. (2019)	Gypsum	mPCM	The fire resistance was reduced greatly and the fire intensity for Light gauge steel-framed wall was increased by using PCM enhanced plasterboard.
[15]	Li, Yu, and Song (2019)	Gypsum mortar	mPCM (PH-31)	The gypsum composite containing micro-PCM reduces the thermal conductivity while it has higher specific heat capacity (2.71 times during the temperature interval from 26 to 32 °C).
[16]	Srinivasaraonaik et al. (2020)	Gypsum board	mPCM (eutectic mixture)	Thermal conductivity and compressive/flexural strength decreases with the introduction of mPCM in gypsum composites

range for longer hours and diminish the building energy usage [8]. A study conducted in Canada demonstrated that applying PCM plasterboard on existing building envelope could decrease the maximum room temperature by up to 4 °C and reduce the heating requirement during the night [19].

Due to the increasing benefits of introducing the PCM-enhanced gypsum plasterboard into the building structure, Numbers of research have examined the performance and effectiveness of gypsum plasterboards embodied with PCM (Paraffin, organic/inorganic PCM). It was indicated that the integration of PCM into gypsum plasterboard could change the complex properties of proposed gypsum composites. The physical, thermal, and mechanical properties such as density, thermal conductivity, compressive strength, which is influenced by the mass fraction and thermal property of the raw materials.

Nevertheless, there is still a great demand for research on analysing the impact of introducing microencapsulated PCM (mPCM) into gypsum blocks in terms of property changes. Hence, this paper aims to develop a gypsum plasterboard incorporated directly with mPCM through thermal/physical property measurement. The heat storage performance of this mPCM-gypsum plasterboard was also examined in this paper.

2. Materials and methods

In this part, the properties and features of the material used for the PCM-gypsum composite preparation are presented, following with approach and instrument for properties measurement. In this study, the PCM-gypsum plasterboard is to be made by mixing multi-finished gypsum and mPCM homogeneously

2.1. Selection of raw materials

Fabrication of PCM-gypsum plasterboard, the multi-finished gypsum was used due to some benefits such as low-cost, common/convenient usage for making gypsum plasters. The mPCM has been effectively implemented in the envelope of buildings [20,21]. Among various types of phase change materials, paraffin has been widely used in buildings due to its advantages e.g. (i) non-corrosive, (ii) non-sub-cooling, (iii) safe to use, (iv) low-cost, (v) higher heat of fusion with reliable, and (vi) stable energy-storing performance [22]. While, encapsulation of PCM is divided into (i) macro-encapsulation (with a diameter of 1 mm and more); (ii) micro-encapsulation (from1 μm to 1 mm); and (iii) Nano-encapsulation (less than 1 μm) [23]. In particular, one of the main advantages of mPCM is that it can be directly mixed with building materials like gypsum plaster or concrete and it achieves a lower heat storage capacity [24]. There is also no damage/leakages between the mPCM and the gypsum during the discharging (melting) process because of the capsule shell and its tiny size [1]. Hence, microencapsulated pure-paraffin powder (MICRONAL® DS 5040X) was selected for making PCM enhanced gypsum plasterboard.

MICRONAL® DS 5040X PCM product is microencapsulated with highly cross-linked polymethacrylate polymer wall which provides a secure containment system for the high-purity paraffin dry powder. Such PCM can be directly used with building materials: conventional plasters, plasterboard, floor screeds, wood, and concrete due to the data from the manufacturer. The easiest way to combine Micronal PCM is to pre-mix it with building material and. It is suggested for adding PCM into gypsum-based systems up to ~ 30% v/v. Therefore, for making PCM-gypsum plasterboard, multi-finished gypsum and microencapsulated MICRONAL® DS 5040X PCM are chosen and the properties are shown in Table 2.

Due to the manufacture information in Table 2, the particle size of the Micronal PCM is in the range from 50 to 300 μm. the peaking temperature was 23 ± 1 °C for the fusion process and 22 ± 1 °C for the crystallization process. Besides, the latent heat storage capacity of this Micronal encapsulated PCM was 95kJ/kg.

2.2. Testing components preparation

Samples were made due to different percentage of additional PCM, Thistle multi-finish plaster, and water was mixed homogenously. The concentration of mPCM is designed to be lower than 30% to secure the mechanical properties and fire resistance feature

Table 2
Properties of the mixtures for casting plasterboard.

Mixture	Density (kg/m^3)	Melting temperature (°C)	Thermal conductivity (W/mK)	Heat of fusion (kJ/kg)
Multi-finished gypsum	1250	–	0.19	–
Micronal DS 5040X PCM	300–400	23 ± 1	0.079	≥ 95
Water	997	0	–	340

of the final product [25]. In this research, the fabrication process of plasterboard was followed as shown in Fig. 1 and each type of plasterboard was made through this process.

There are 4 different types are namely: (i) gypsum board, (ii) gypsum board with 5% PCM, (iii) gypsum board embodied with 10% PCM, and (iv) gypsum plasterboard integrated with 15% PCM (Table 3).

As the fabrication process is shown in Fig. 1, the raw materials were mixed uniformly before pouring into a wooden mould having a size of$400 \times 400 \times 10mm$. The moisture of the material can significantly affect the thermal conductivity and the samples is dried for about 28 days after casting according to the provisions of IS EN 1290-2. The dried samples were used for various measurement to characterise the physical and thermal properties. Those measurements were thermal conductivity testing, density measurement, compressive strength test, and SEM testing.

2.3. Property measurement of PCM-gypsum plasterboard

It is important to characterise the PCM-gypsum plasterboard because the addition of PCM might change the physical/thermal properties of the plasterboard. Hence, four different measurements were carried out and those were namely: Scanning Electron Microscopy (SEM) analysis, thermal conductivity test, density measurement, and compressive strength. Such measurements also enabled to highlight the additional benefits of additional PCM into gypsum plasterboard fabrication. During measuring each property, each type of plasterboard had at least 3 samples and each testing was performed more than 3 times. The results were displayed with a 98% confidence interval and were compared with the standards for gypsum plasterboard manufacturing.

(i) SEM analysis

Scanning electron microscope (SEM) is an electron microscope that scans the surface using a focused electron beam and then produces an image containing information about the surface topography and chemical composition [26]. In order to examine the distribution of each compositions inside the final PCM incorporated gypsum plasterboard, the samples were tested using secondary electron (SE) in a Zeiss Gemini Sigma 500VP scanning electron microscope (SEM) and Energy-dispersive X-ray spectroscopy (EDS) in Coventry University, UK (Fig. 2). EDS is an analytical technique to determine the elemental compositions or chemical characterisation of the material [27].

According to Fig. 2, four samples with the dimension of $5 \times 5 \times 2$ mm (height: width: thickness) from PCM-gypsum plasterboard and gypsum plasterboard separately were tested through SEM device and the average results of four samples were presented. The samples did not require a coating method to be electrically conductive due to their tight thickness.

(ii) Thermal conductivity test

Thermal conductivity is a pure and basic material property that affects the thermal performance of a material. The addition of PCM changes the thermal conductivity of PCM enhanced gypsum plasterboard so that it's significantly important to undertake the thermal conductivity testing. The guarded hot plate method through FOX 314 Heat Flow Meter (HFM) is used to run steady-state thermal conductivity of specimens (Fig. 3). During this testing, a sample with the size $200 \times 200mm$ is placed between two different states of hot and cold plates where the heat flows in a steady form through the sample square cross-section, and the temperature difference between two surfaces are recorded. One of the upper or lower plates is powered by stepper motors positioned in each corner, and another one is touched with the sample. Following Eq. (1), the testing device would give the result of thermal conductivity for each sample at the end when the testing finished automatically. The instrument settings are following the European regulation on thermal conductivity measurement.

$$k = \frac{U \cdot I \cdot L}{a \cdot b \cdot (T_h - T_c)} \tag{1}$$

Where, U and I are the voltage and current supply of electric heater; L refers to the thickness of a sample; a and b are the lengths of sides of a sample; T_h and $T_c$efine temperature of the electric heater (hot plate) and the temperature of the cold plate, respectively;

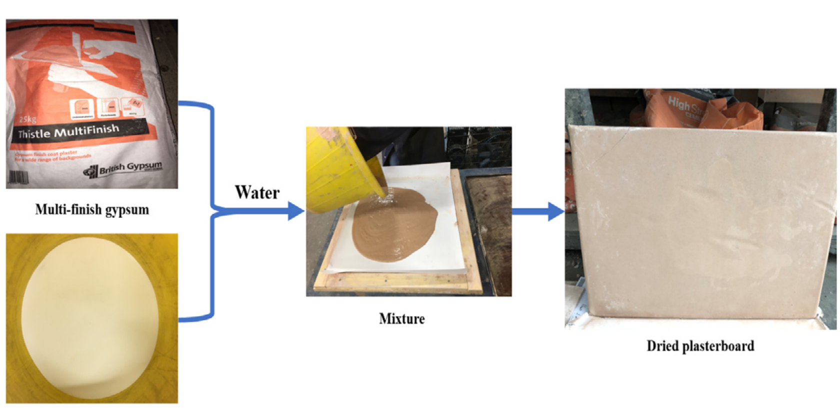

Fig. 1. The fabrication process of Plasterboard in the lab.

Table 3
Various type of testing component samples.

Sample type	Abbreviation	Gypsum (v/v%)	PCM (v/v%)	Water (v/v%)
Gypsum plasterboard	A	50	0	50
PCM-enhanced gypsum plasterboards	B1	45	5	50
	B2	40	10	50
	B3	35	15	50

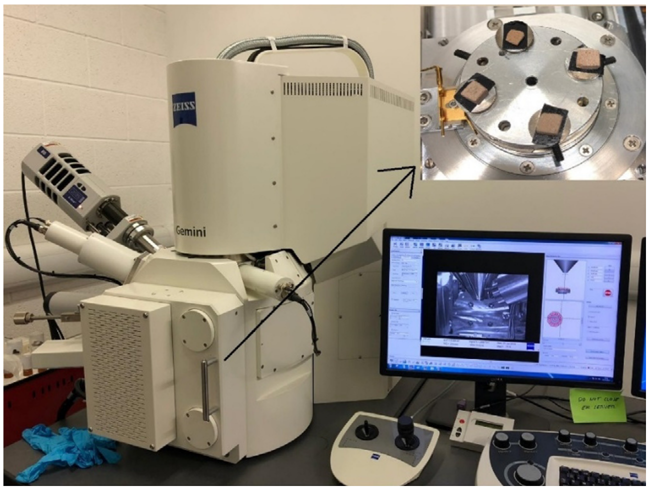

Fig. 2. Schematic of SEM instrument in Coventry University.

(iii) Density measurement

The density is determined by separating the total weight of each ingredient by volume. The specimen dry weight is tested first before putting into the water container for measuring the wet weight of the samples under the normal lab condition. The samples are placed in a sealed water container and the growth in water height represents the volume of plasterboard without any voids or moisture (Fig. 4). Lastly, the density of the gypsum plasterboard was calculated by the below Eq. (2):

$$Thedensityofsample = \frac{Dryweight \times Densityofwater}{Dryweight - Wetweight} \quad (2)$$

(iv) Compression strength check

The compressive strength is the ability of the gypsum board to withstand the load tending to reduce the size, and it is usually experimentally determined by a compressive strength test. It determines how the gypsum board reacts when compressed, crushed, crushed or flattened to assess the strength of the gypsum board [17]. This also helps us to ensure that the newly designed gypsum board is of high quality. Hence, the compression strength of the PCM reinforced gypsum plasterboard was tested by "Cube Crushing" Compression testing Machine in Coventry University Structural lab (Fig. 5).

Fig. 4. Schematic of density testing device.

Fig. 3. Schematics of FOX 314 Heat Flow Meter instrument.

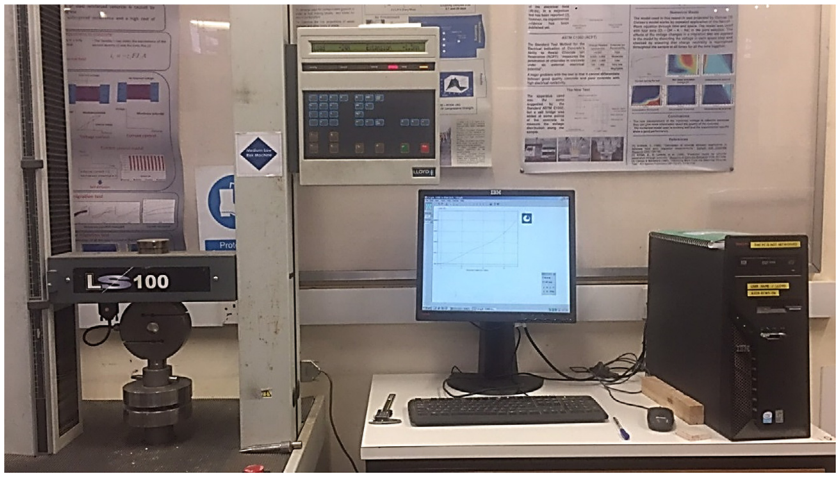

Fig. 5. Schematic of "Cube Crushing" Compression Testing Machine.

During the test, the test load will be applied at the uniform rate of 1 N/mm^2s and the load rate will be added automatically until the plasterboard changes its size. During this process, the applied load will be also recorded by a computer. Therefore, the test procedure will be repeated for the samples with different phase change materials. The compressive strength (σ) of each sample was automatically calculated and displayed by a computer by the following Eq. (3), which is then compared with the European standard EN 13279–2: 2004.

$$\sigma_e = \frac{F}{A_o} \tag{3}$$

Where,F = Load applied$[N]$, A_o = original specimen area $[m^2]$.

2.4. Characterisation result and discussion

According to the characterisation procedure mentioned above, the thermal/physical properties of samples was carried out in terms of thermal conductivity, SEM, density and compressive strength measurement. During each property testing, each type of sample had at least 3 pieces with the same combination ratio of gypsum and PCM and each sample were tested more than three times. Such process enables to reduce the measurement uncertainty and increase the accuracy and credibility of the measurement data. In this study, such testing approach assures that the data used for further analysis and discussion in this study are reliable with higher credibility. Hence, the characterisation results cover SEM analysis, compressive strength test, density measurement, and thermal conductivity. Each of them is explained in detail as below.

2.5. SEM analysis

The SEM/EDS instrument was used to do SEM analysis for two samples: (i) gypsum plasterboard and (ii) gypsum plasterboard with MICRONAL® DS 5040X PCM powder and the results are shown in Fig. 6.

Fig. 6 shows the formation of highly interlocking acicular gypsum crystals during the hydration of the hemihydrate. These needles exhibit at a typical μm size, so it is expected that particles of similar size will have a large effect on gypsum properties. In Fig. 6, there were needle shape of a component and several spherical shapes of apparatuses and It can be estimated that the diameter of capsules is in the range of ideal size of microencapsulated MICRONAL® DS 5040X PCM powder [28,29].

Fig. 7 shows the surface analysis of the dried PCM enhanced gypsum plasterboard and the EDS analysis of three different spectrum. The EDS analysis indicated that there are different major compositions separately in three spectrum points in Fig. 7a. In return, it could represent various chemical compositions. For instance, the silica shell at spectrum point 1 displays Calcium (Ca) and Sulphur (S) represents the chemical formula of gypsum that can be seen in Fig. 7b. Meanwhile, silicon (Si) and oxygen (O) demonstrated more at the point of spectrum 3 (Fig. 7d). The spectrum point 3 shows more the chemical composition of O and then Si as the core of MICRONAL® DS 5040X PCM powder has SiO_2 [30]. Hence, the results of SEM imaging and EDS analysis of the PCM-enhanced gypsum plasterboard sample can be valid due to the previous knowledge/formula on the encapsulation process [31,32].

2.6. Compressive strength test

It was investigated to check if the compressive strength of the gypsum composites integrated with mPCM could satisfy the mechanical regulations of European standard.

Fig. 8 shows the maximum compressive strength of various gypsum composites filled with different concentrations of phase change materials. The results show that increasing the amount of phase change material added reduces the maximum compressive strength. For example, the addition of 5% and 15% PCM enhances the compressive strength of the gypsum board to 5.36 and 4.34 MPa, respectively. However, the results indicate that the proposed PCM reinforced gypsum board is eligible for use in construction due to the obligation that the building structure requiring gypsum board is at least 2 MPa or exceeds the maximum compressive strength (EN 13279–2) [6,30].

2.7. Density results

The density measurement was made using the instrument (Fig. 4) and calculated using Eq. (2). During this test, each type of sample was tested at least 3 times and the averaged results are shown in Fig. 9.

According to Fig. 9, increasing the content of the PCM reduces the bulk density because PCM has a smaller particle size than the gypsum particles and will fill the position between the gypsum particles. Therefore, the gypsum plasterboard filled with 15% PCM has the minimum density of 1549.0Kg/m^3 due to the lowest density of the mPCM. The bulk density requirement for all samples is greater than 600Kg/m^3, which is in accordance with standard EN 13279-2 [6]. However, due to the difference in the manufacturing

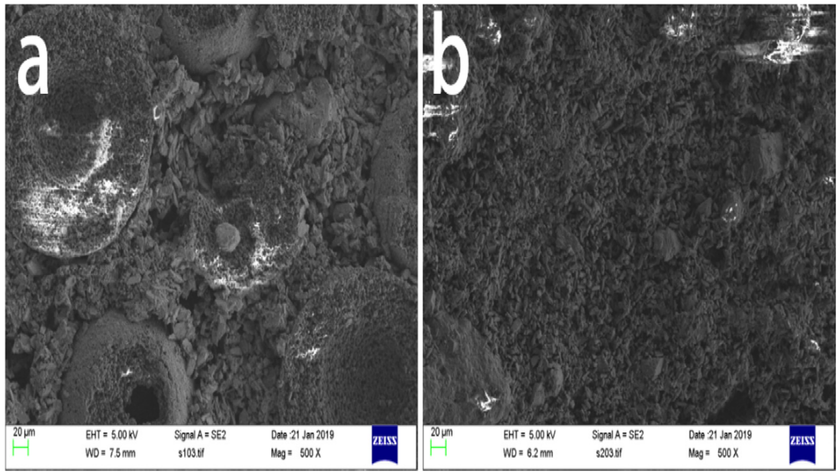

Fig. 6. SEM image of (a) PCM-gypsum plasterboard and (b) gypsum plasterboard.

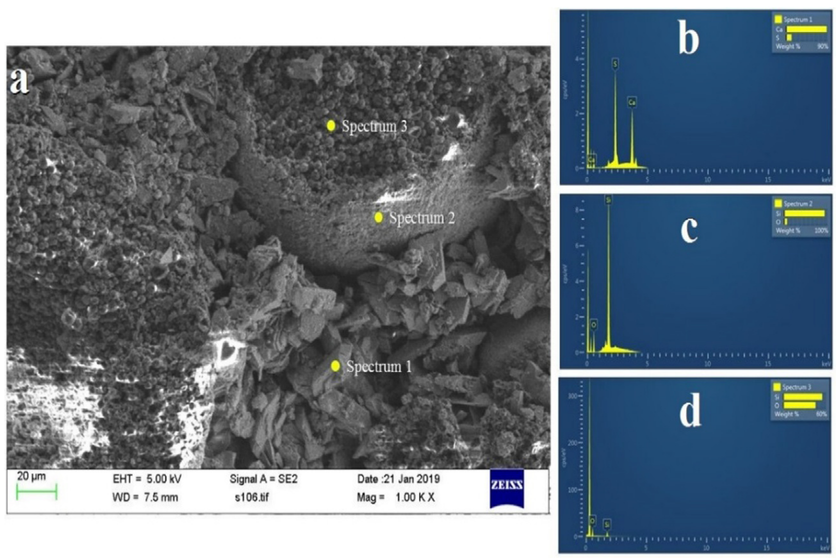

Fig. 7. SEM micrographs of (a) surface analysis of gypsum plasterboard enhanced PCM and (b, c, d) corresponding EDS analysis of yellow spectrums in (1, 2, 3). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

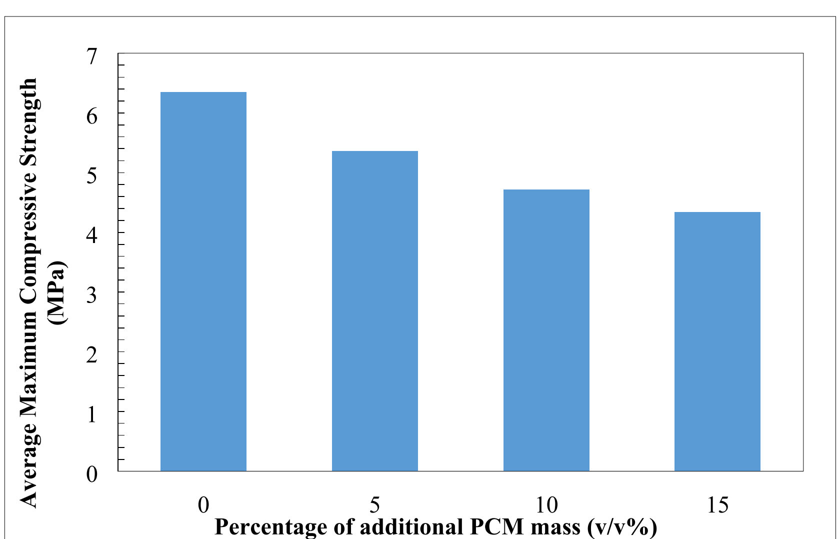

Fig. 8. The maximum compressive strength of the gypsum plasterboard with various percentage of additional mPCM.

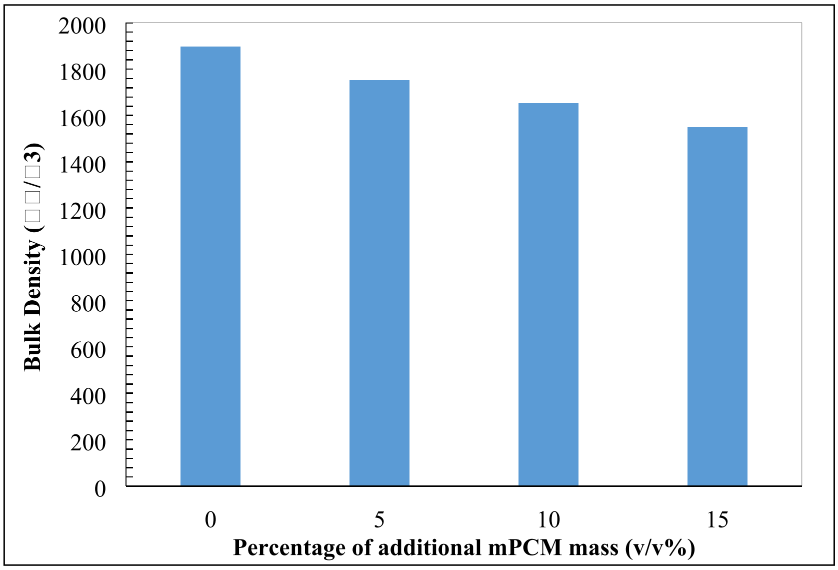

Fig. 9. Average bulk density for each type of gypsum block.

process of the gypsum board, the density results may vary with respect to the density of the commercial gypsum board.

2.8. Thermal conductivity of gypsum blocks

Measuring the thermal conductivity is one of the key factors determining the property because it affects the heat flux and specific heat capacity of the gypsum plasterboard. In this study, the thermal conductivity of the sample was tested through HFM. The thermal conductivity of each type of gypsum board was measured at least three times. All samples were the same size and different compositions. The average results for each sample are shown in Fig. 9. Also, the measurement accuracy is ± 1%.

An increase in PCM concentration reduces thermal conductivity because PCM has a lower thermal conductivity and minimizes the total thermal conductivity of the sample. For example, the thermal conductivity of all cast gypsum boards is not greater than0.16 W/mK, which is lower than the thermal conductivity of 0.19 W/mK of the manufactured gypsum board (Figs. 4–11). Besides, among all types of gypsum board samples, the gypsum composite with 15% PCM had the lowest thermal conductivity of 0.139 W/mK. It can be indicated that the addition of PCM can reduce the thermal conductivity of the gypsum board and has a higher heat insulating ability than the gypsum board manufactured. Therefore, PCM-reinforced gypsum plasterboard is one of the promising materials for construction.

2.9. Charging/discharging of mPCM plasterboard

The mPCM-plasterboard was made by mixing multi-finished gypsum and 15% of mPCM homogeneously. It is suggested for adding PCM into gypsum-based systems up to ~ 30% v/v (volume per volume) due to the technical data from the manufacture. The microencapsulated pure-paraffin powder (MICRONAL® DS 5040X) was selected for making this mPCM-gypsum plasterboard. The properties for the raw materials are shown in Table 2.

The raw materials (multi-finished gypsum, Micronal DS 5040X PCM, and water) were mixed homogeneously and poured into a wooden mold and two different types of plasterboard with the same dimension of 950 × 1000 × 10*mm* (height: width: thickness)

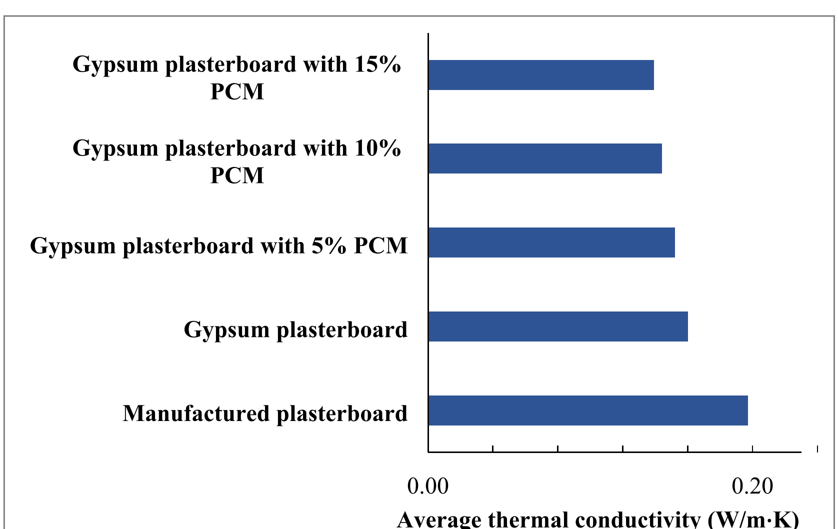

Fig. 10. Average thermal conductivity for each type of gypsum block.

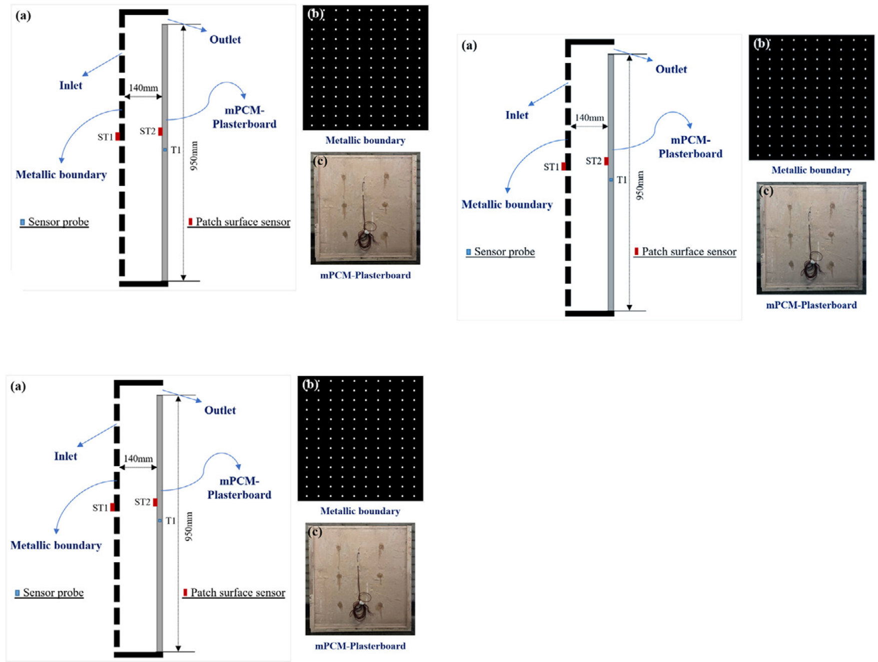

Fig. 11. Schematics of (a) experimental platform; (b) Metallic boundary; and (c) mPCM plasterboard.

were fabricated and dried for about 28 days in Coventry Structural Lab in September 2018 (Fig. 11c). There are probe sensor to measure internal temperature of plasterboard and patch sensor to record surface temperature (ST) of plasterboard.

A metallic boundary as heating source was located 140 mm away from the plasterboard to examine the charging and discharging behaviour of mPCM plasterboard in this study (Fig. 11a). The metallic boundary was designed to be heated for 135 min and then to be cooled down naturally (Fig. 11b). During this process, the temperature at different positions was measured through PT100 (Probe and Patch) sensor as: Metallic boundary temperature (ST1), surface temperature of PCM-gypsum plasterboard (ST2), and inside temperature of PCM-gypsum plasterboard (T1). The results showed the metallic boundary reached its highest temperature of 60 °C within the very shortest time due to its higher thermal conductivity (Fig. 12).

The PCM-plasterboard (inside and surface) temperature displayed an increasing trend within the first 60 min and then it increased slowly between 60 and 135mins where the mPCM proportion were assumed to be fully melted and relatively steady-state with the final temperature of approximately 45.5 °C. During discharging period, the metallic boundary temperature went down dramatically fast within 30mins. However, the mPCM-gypsum plasterboard inside/surface temperature was declined slowly to a relatively lower temperature (20 °C). That was possible due to the addition of mPCM where the mPCM stored a certain amount of latent heat during the charging period and release slowly during the discharging period [33].

Under the same experimental conditions, gypsum plasterboard was tested for charging/discharging behaviour. The temperature variation for mPCM-gypsum plasterboard and gypsum plasterboard during charging/discharging period was presented in Fig. 13. A similar temperature trend (rapid increase within first hour and relatively stable after 60 min) for the gypsum plasterboard and mPCM-gypsum plasterboard temperature was displayed. During charging period, gypsum plasterboard temperature reached higher temperature rapidly than mPCM-gypsum plasterboard (Fig. 13). The gypsum plasterboard temperature continues to rise until it is extinguished, and its final temperature (46.8 °C) was higher than that of the mPCM gypsum plasterboard (45.5 °C). It can be estimated that the mPCM gypsum plasterboard was completely melted as its temperature to remain relatively stable where it store energy.

During discharging period, the gypsum plasterboard temperature drops faster and have lower temperature than the mPCM-gypsum plasterboard (Fig. 13). For instance, at 210 min point, the gypsum plasterboard and mPCM-gypsum plasterboard temperature were declined to 24.5 and 22.5 °C respectively. One possibility was that the mPCM-gypsum plasterboard released the stored energy during discharging period because of the additional mPCM in the gypsum plasterboard. It can be concluded that the mPCM-gypsum plasterboard operates longer than gypsum plasterboard with higher temperature of roughly 1.5 °C especially during discharging period.

In addition, the stored energy (Q_s) from both two cases can be calculated by the following Eq. (2) and the result is showed in Fig. 10.

$$Q_s = mc_p(T_p - T_{in-lab}) \tag{4}$$

Where, Q_s is the stored energy; m is mass of plasterboard, c_p represents the specific heat capacity of plasterboard; T_p gives plasterboard temperature, and T_{in-lab} is the in-lab ambient temperature.

Fig. 14 displayed that there was a slight difference in the energy stored from both because of the addition of mPCM in plasterboard. In the charging period, the gypsum stored higher amount of energy as certain amount of energy was used to melt the mPCM inside the gypsum plasterboard where energy stored as latent. However, the mPCM-gypsum plasterboard was not storing a huge amount of energy due to the small proportion of mPCM used in the PCM-gypsum plasterboard in this study.

During discharging period, mPCM-gypsum plasterboard released the stored latent heat than the one with the gypsum plasterboard. On average, the mPCM-pasteboard provided 0.4 W/min higher energy stored than the one with gypsum plasterboard due to the addition of mPCM (Fig. 14).

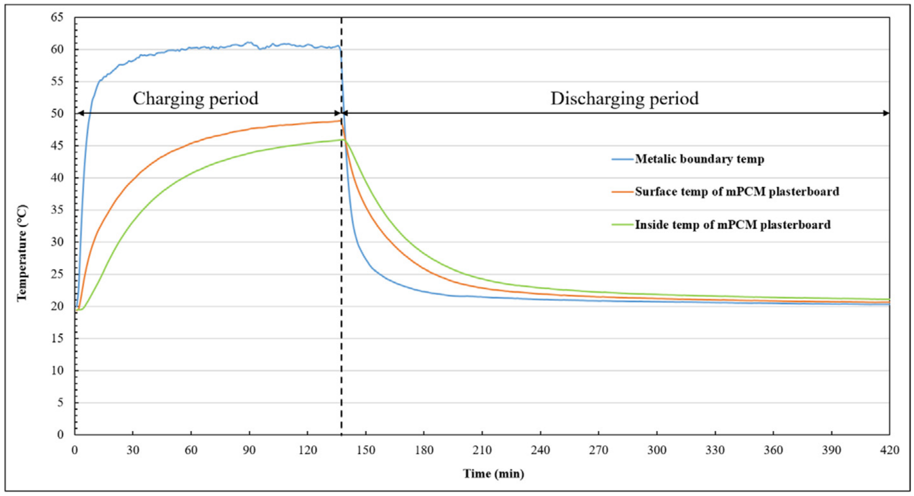

Fig. 12. Temperature distribution of PCM plasterboard.

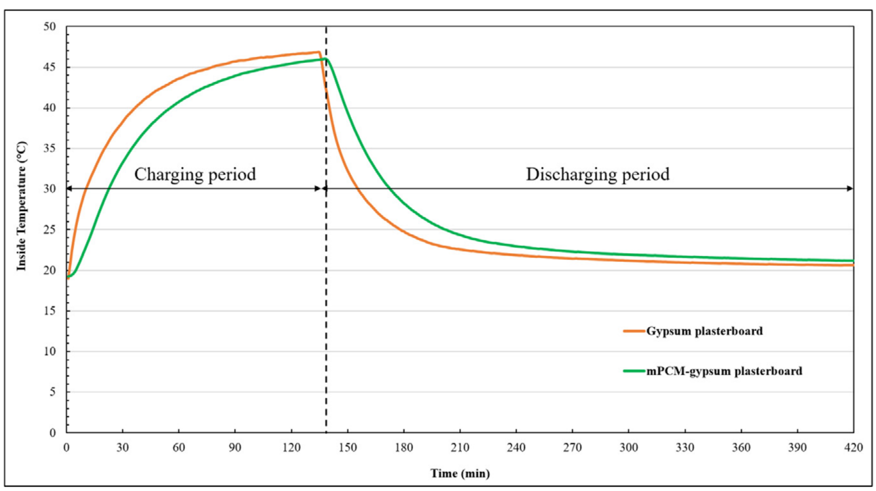

Fig. 13. Temperature of mPCM-gypsum plasterboard and gypsum plasterboard.

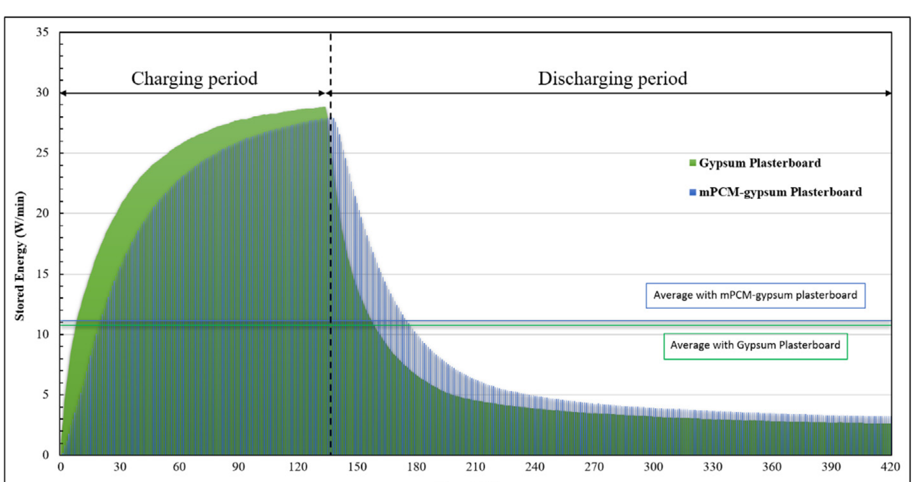

Fig. 14. Stored energy with mPCM-gypsum plasterboard and gypsum plasterboard.

3. Conclusions

This Study mainly focused on the characterization of the developed gypsum plasterboard integrated with mPCM (MICRONAL® DS 5040X PCM powder). The properties testing included bulk density measurement, thermal conductivity testing, compressive strength measurement, and SEM testing. The heat storage performance of mPCM-gypsum plasterboard was analysed. Hence, this work conducted the following results.

a) SEM image shows that multi-finished gypsum powder and mPCM were mixed uniformly and the MICRONAL® DS 5040X PCM powder can be seen clearly from the photograph of SEM testing.
b) The density measurement indicated that increasing mPCM content decreases the bulk density. For instance, the gypsum plasterboard filled with 15% PCM has the minimum density as $1549.0Kg/m^3$ due to the lowest density of the mPCM.
c) An increasing amount of mPCM additions would reduce the maximum compression strengths of gypsum boards. The gypsum plasterboard enhanced with 5% and 15% mPCM claim 5.36 and 4.34 MPa respectively.
d) Through thermal conductivity testing, the gypsum boards with the addition of 15% mPCM had the lowest value of thermal conductivity as 0.139 W/mK among all plasterboard samples. Hence, the increasing concentration of mPCM would results in the lower thermal conductivity since the PCM has a lower thermal conductivity that enables to minimize the total thermal conductivity of produced gypsum composite.
e) The mPCM-gypsum plasterboard operates longer than gypsum plasterboard with higher temperature of roughly 1.5 °C especially during discharging period.
f) The mPCM-pasteboard provided 0.4 W/min higher stored energy than gypsum plasterboard due to the addition of mPCM (11.5 W/min compared to 10.75 W/min on average).

Conflict of interest statement

Authors declare that there is no conflict of interest among them. All authors have been given name in the manuscript as per their contribution.

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